INTL J BONOROWO WETLANDS
Volume 12, Number 1, June 2022
Pages: 23-32

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w120103

Benthic infaunal spatial biodiversity, coexistence, and availability for shorebird communities in the Jakarta Coastal Wetlands, Indonesia

ANDRIO A. WIBOWO[1,♥], ADI BASUKRIADI[1], ERWIN NURDIN[1], NANA SURYANA NASUTION[2]
[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Prof. Dr. Sudjono D. Pusponegoro, Depok 16424, West Java, Indonesia. Tel.: +62-21-727-0163, ♥email: awbio2021a@gmail.com
[2]Faculty of Teacher Training and Education Science, Universitas Singaperbangsa. Jl. HS. Ronggo Waluyo, Telukjambe Timur, Karawang 41361, West Java, Indonesia

Manuscript received: 4 May 2022. Revision accepted: 8 June 2022.

Abstract. *Wibowo AA, Basukriadi A, Nurdin E, Nasution NS. 2022. Benthic infaunal spatial biodiversity, coexistence, and availability for shorebird communities in the Jakarta Coastal Wetlands, Indonesia. Intl J Bonorowo Wetlands 12: 23-32.* Wetlands on the Jakarta Coast, Indonesia, is one of the important habitats for shorebirds. In the wetland ecosystem, benthic infauna is an important food source for the shorebird community. This study aims to assess the benthic infaunal spatial biodiversity and its availability for the shorebird community in the wetlands covering an ecotourism area and the west and east parts of a protected mangrove forest. The bird diversity was assessed using visual encounter surveys and 10 x 10 m plots for mangroves. The K-means clustering method measured the benthic infaunal coexistence and availability for shorebirds. Based on the result, benthic infauna was available as a food resource for shorebirds in the following order: Oligochaeta > Polychaeta > Gastropod > Crustacea, with the density of oligochaetes reaching 376.66 inds/100 m^2. The Shannon-Wiener biodiversity index (H') ranges for benthic infauna were 1.306-1.573. Gastropods were available to Ciconiidae and Anhingidae; oligochaetes and polychaetes were available to Anatidae, Scolopacidae, and Phalacrocoracidae. In contrast, crustaceans were not available to any shorebird species. As confirmed in this study, shorebird species were associated with the presence of benthic infaunal communities and it recommends conserving the wetlands to ensure the availability of benthic infauna.

Keywords: Biodiversity, K-means, mangrove, Oligochaeta, spatial

Abbreviations: GIS: Geographical Information System, GPS: Global Positioning System, SAGA: System for Automated Geoscientific Analyses

INTRODUCTION

Coastal ecosystems, with their wetland areas, are vital to shorebirds (Rija et al. 2015; Amarasekara et al. 2021) and also benthic infaunal communities (Rabalais and Baustia 2020). The Ramsar Convention on Wetlands defines wetlands as areas of marsh, fen, peatland, or water, whether natural or man-made, permanent or temporary, containing water (Gaget et al. 2020). Wetlands are among the world's most productive ecosystems, as well as in Indonesia. Furthermore, for thousands of years, those wetlands have provided food, drinking water, building materials, and many other services to human populations. Wetlands also play an important role in preserving global biodiversity, partly through their high production, which supports food chains, and partly by providing habitat for especially suited plant and animal species, including benthic infauna and shorebirds.

Wetlands in Indonesia are characterized by vast mangrove cover. Indonesia has 3 million ha or 23% of the world's mangrove area (Murdiyarso et al. 2015). Those wetlands and mangroves in Indonesia are important habitats for shorebird communities. For example, in the wetlands of Panjang Island Coast, Jepara, Central Java, there were 27 shorebird species from 15 families, with the biodiversity index of the shorebird species ranging from 1.15 to 2.20 (Utami et al. 2017). At Maron Beach, Prasetyo and Wulandari (2021) reported that there were 42 bird species from 20 families, with a Shannon-Wiener biodiversity index (H') of 2.915. Meanwhile, in the wetlands of Tegal Coast, Central Java, there were 37 bird species from 18 families, with H' values that ranged from 2.22 to 2.37 (Isworo and Oetari 2020).

Benthic infauna includes molluscs, polychaetes, oligochaetes, and crustaceans (Rabalais and Baustia 2020). Wetlands in Indonesia, particularly those on Java Island Coast, were also important habitats for benthic infauna (Andriyono et al. 2016). Then, Sahidin et al. (2014) reported a total of 5458 individuals of benthic infauna with a density ranging from 177 inds/m^2 to 634 inds/m^2 in Tangerang Coast, Banten. In the mangrove ecosystems on the Pacitan Coast, East Java, benthic infaunal diversity represented by molluscs has H 'values of 2.14, with 17 gastropod species belonging to 13 families (Wiraatmaja et al. 2022). For polychaetes and crustaceans, Katili and Utina (2019) reported that mangrove *Rhizophora* sp. contained more polychaetes and crustaceans than other mangrove species. In the Musi River wetland, the range of Polychaeta density was 1.054-2.831 inds/m^2 (Sari et al. 2022).

The presence of benthic infauna is very important as a food resource for shorebird communities. The distribution of shorebird communities in the wetlands is influenced by the distribution and availability of benthic infauna, including crustaceans, polychaetes, and oligochaetes (Pérez-Vargas et al. 2016). In the same way that the other coasts on Java Island have a wetland, Jakarta also has a wetland. Despite the abundance of studies on the distribution and abundance of shorebird and benthic infaunal communities along the Jakarta Coast, interactions, the spatial distributions of shorebirds, and the spatial availability of their prey, that is, the benthic infaunal communities were rarely investigated. This study is becoming more important recently since there has been a massive change in wetlands on the Jakarta Coast that has led to the reduction of wetland ecosystems (Sasongko et al. 2014; Sofian et al. 2019), followed by the decline of the benthic infaunal communities and shorebird communities. Here, this study aims to assess the benthic infaunal spatial biodiversity and its availability for the shorebird community in the wetlands of the Jakarta Coast, Indonesia.

MATERIALS AND METHODS

Study area

The study areas included 3 sampling locations selected based on the presence of mangroves in the wetlands of Jakarta Coast, Indonesia (Table 1), including an ecotourism park with latitude coordinates of 6.099^0-6.116^0 South and a longitude of 106.728^0-106.736^0, and the east and west parts of the Angke Kapuk protected forest with latitude coordinates of 6.099^0-6.116^0 South and a longitude of 106.736^0-106.769^0 (Figure 1). Fish ponds in the west bordered the ecotourism park. In contrast, the western parts of the Angke Kapuk protected Jakarta Bay, bordered by forest in the north and fish ponds in the west. The eastern parts of the Angke Kapuk protected forest are bordered by Jakarta Bay in the north and the Angke River in the east. Settlements in the south bordered all of the study areas. Regarding the study area's hydrological conditions, all of the study areas were wetlands that were permanently influenced by the tide and inundated by water.

Procedures

Shorebird survey

The shorebird survey in the wetlands of Jakarta Coast, Indonesia, was conducted for two months, from July to August 2021 with 3 replications for each location. The survey techniques included audiovisual encounter surveys and multiple surveys through random visits involving 2 observers (Buda and Budka 2019). The survey was conducted during various periods of the day using direct observations supported by binoculars and unaided eyes. Based on the bird activities, the survey was conducted from 05.30-7.00 am and continued at 04.00-06.15 pm with at least 2-3 sampling hours. The shorebird species richness of three distinct study areas, including an ecotourism park, west and east parts of Angke Kapuk protected forest, was recorded. The identification of birds was done using a bird identification book and field guide (MacKinnon and Phillipps 1993). The presence of birds is then tabulated into a Geographical Information System (GIS) to be mapped into mangrove and land cover thematic layers. The abundance of shorebirds was calculated as the number of individuals seen within a 100 m x 100 m plot and denoted as inds/Ha (Obunga et al. 2022).

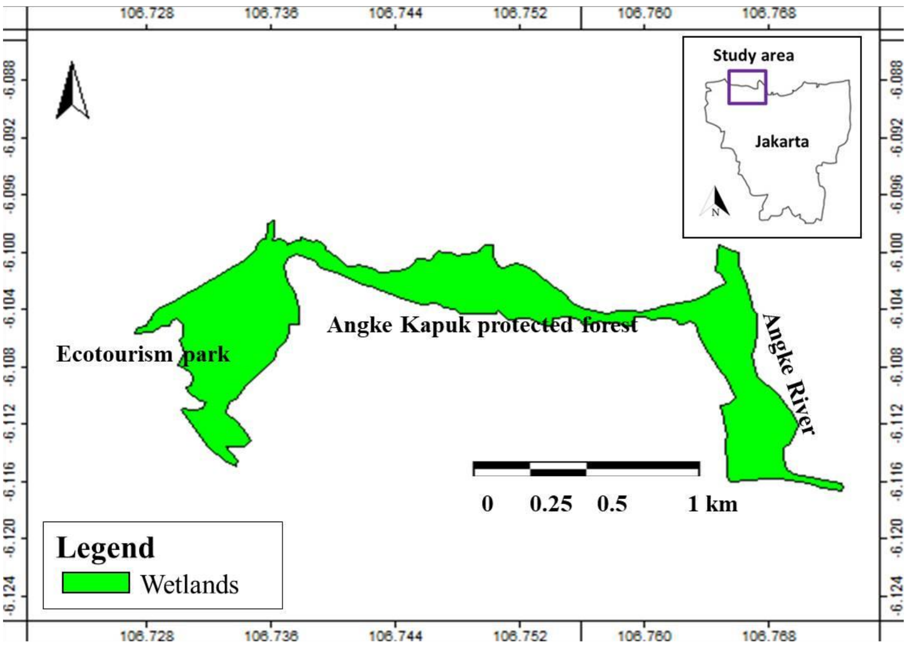

Figure 1. A map of the study area shows three study areas located in an ecotourism park and the west and east parts of the Angke protected forest in the wetlands of Jakarta Coast, Indonesia

Table 1. Locations and descriptions of the study area in the Jakarta Coast, Indonesia

Study area	South latitude	East longitude
Ecotourism park, bordered by fish ponds in the west	6.09^0 S - 6.116^0 S	106.728^0 E - 106.736^0 E
West parts of Angke Kapuk protected forest, bordered by Jakarta Bay in the north and fish ponds in the west	6.09^0 S - 6.116^0 S	106.736^0 E - 106.748^0 E
East parts of Angke Kapuk protected forest, bordered by Jakarta Bay in the north and Angke River in the east	6.09^0 S - 6.116^0 S	106.748^0 E - 106.769^0 E

Benthic infaunal survey

The benthic infaunal survey was conducted using the purposive random sampling method following Basyuni et al. (2018) by making observation plots with the size of each plot being 10 x 10 m or equal to 100 m^2. Each individual benthic infauna was collected from the substrate at a depth of 10 cm considering the maximum length of shorebird bill (Pérez-Vargas et al. 2016) using a 0.1 m^2 Van Veen Grab and sieved using a mesh sieve sized 0.5 mm to separate the benthic infauna from the sediment (Sahidin and Wardiatno 2016). The collected benthic infauna was then identified and its coordinates were recorded using a Garmin Etrex Global Positioning System (GPS) handheld device at the observation plot. The benthic infauna was identified using a benthic infauna identification book and field guide (Sahidin 2020). The presence of benthic infauna was then tabulated into a Geographical Information System (GIS) to be mapped into mangrove and land cover thematic layers.

Shorebird and benthic infaunal biodiversity index Shannon Wiener (H')

The biodiversity of shorebird and benthic infaunal communities was assessed using the biodiversity index Shannon-Wiener (H') with the following equation: $H' = \Sigma[Pi \ln (Pi)]$, where Pi is the proportion of the individuals i shorebird and the benthic infauna in total individuals. The H' range is from 0 (low diversity) to > 1 (high diversity).

Mangrove survey

The mangrove survey was conducted using the purposive random sampling method following Hutabarat (2009) and Sofian et al. (2012) by making observation plots with the size of each plot being 10 x 10 m. Each individual mangrove tree was identified and its coordinates were recorded using a Global Positioning System (GPS) handheld device at the observation plot. Mangrove species identification was conducted using a mangrove identification book and field guide (Chapman 2016; Hirsch 2016; Tomlinson 2016). The recorded mangrove species are then tabulated for further mangrove and land cover mapping.

Mangrove, land cover, shorebird, and benthic infaunal spatial analysis

Mangrove, land cover, shorebird, and benthic infaunal spatial analysis in the wetlands of Jakarta Coast was performed using remote sensing and GIS analyses using SAGA (System for Automated Geoscientific Analyses) GIS version 2.1.2 (Alevizos 2016) following Orimoloye et al. (2019), Philiani et al. (2016), and Sukojo and Arindi (2019). Landsat 8 satellite imagery of Jakarta Coast was retrieved and classified using supervised classification to determine the land cover types. The categories for land cover classifications were mangroves, water bodies, fish ponds, and settlements. The result of mangrove and land cover mapping is a thematic layer. The coordinates of shorebird and benthic infauna are then overlaid with the mangrove and land cover mapping for further analysis and interpretation.

Data analysis

K-means clustering

The availability and coexistence of benthic infaunal for shorebird communities were assessed and measured statistically using K-means clustering (D'Andrea et al. 2019). Suppose the benthic infaunal and shorebird communities were clustered together in one cluster. In that case, it indicates that the benthic infaunal and shorebird communities were overlapping, and the shorebird could utilize the benthic infauna as their food resources. Cluster methods follow current methods to determine the concentrations and hotspots of the benthic infaunal and shorebird communities in 3 studied areas (Zhao et al. 2019). The input data were the abundances of benthic infauna and shorebirds in each study area and were presented as points in the GIS interface. Cluster analysis was conducted using an extension of GIS and the cluster calculation was based on the K-means method. This method uses an algorithm that assigns each point to the cluster whose center, or known centroid is nearest. The center is the average of all the points in the cluster, and the coordinates of the points are the arithmetic mean for each dimension separately over all the points in the cluster. The determination of the centroid, or cluster point, was as follows:

$$z_1=(x_1+y_1)/2,\ z_2= (x_2+y_2)/2,\ z_3=(x_3+y_3)/2$$

Where: z = centroid, x = coordinate in axis x, y = coordinate in axis y

x^2 analysis

The goodness of fit (x^2) statistical test was performed to assess the different significance of benthic infauna among study areas. The significance level was $p < 0.05$.

Correlation analysis using Akaike Information Criterion (AIC)

Correlation analysis based on Akaike Information Criterion (AIC) was used to assess the correlation and dependence of shorebird species with benthic infaunal communities. The AIC was developed using linear regression with straight-line fit equations of $y_i = b_0 + b_1x_i + \varepsilon_i$. The ε_i represents the residuals from the straight line fit. If the ε_i is considered to be i.i.d. (independent and identically distributed) Gaussian with zero mean, the model contains three parameters: b_0, b_1, and the Gaussian distributions' variance. As a result, we should use k = 3 when calculating the AIC value of this model. In general, the variance of the residuals' distributions should be counted as one of the parameters in any least squares model using i.i.d. Gaussian residuals. The measured parameters included in AIC, AICc, ΔAIC, AIC weight, AIC cum., and Loglikehood values. To build the model, shorebird density variables correlating with benthic infaunal density variables were included in the analysis to develop the model and assess the dependence of both variables. The best model was selected based on the model that has the lowest AIC values.

RESULTS AND DISCUSSION

Mangrove and land covers

Land covers along with their mangrove covers on the study area in the wetlands of Jakarta Coast can be seen in Figure 2. The land cover consists of mangrove cover and is followed by combinations of water bodies and fish ponds. Mangrove cover was very dense in the west and east parts of the Angke Kapuk protected forest and less in the ecotourism park. In contrast, water bodies and fish pond combinations were more common in the ecotourism parks and fewer in the protected forest. The presence of water bodies in the eastern parts of the protected forest was due to the presence of the Angke River, located on the east side of the protected forest. A common settlement was found on the protected forest's southern border and the ecotourism parks' east side. The mangroves in the study area were dominated by *Rhizophora* sp. The density of mangrove *Rhizophora* sp. ranged from 3807.2 trees/ha to 1399.5 trees/ha.

Benthic infauna and shorebird communities associations with the wetlands

The benthic infauna in the wetlands consisted of individuals belonging to polychaetes, oligochaetes, gastropods, and crustaceans. The benthic infaunal species include *Melanoides* sp., *Pomacea* sp., *Littorina* sp. for gastropods, *Tubifex* sp. for oligochaetes, and *Nereis* sp. for polychaetes. The ranges of H' for benthic infauna were 1.306-1.573. The density of benthic infauna was significantly different ($p < 0.05$) in each study area (x^2 = 464.848, $p < 0.001$), indicating influences and effects of study area locations and land covers. Among benthic infauna, oligochaetes have the highest density (376.66 inds/100 m^2), followed by polychaetes, and crustaceans have the lowest density (3.333 inds/100 m^2). According to the study area, the protected forests have the highest benthic infaunal density with a range of 108.442 inds/100 m^2 to 263.441 inds/100 m^2 and the lowest benthic infauna density was found in an ecotourism park with a value of 81.77 inds/100 m^2. Despite the lowest benthic infaunal density in the ecotourism park, this study area has more benthic infauna species compared to other study areas due to the presence of crustaceans (Figure 3). The high density of benthic infauna in the west and east parts of the Angke Kapuk protected forest was due to the dominance of oligochaetes, followed by polychaetes. In this study area, oligochaetes were present more than 50% of the time, as observed in the wetlands of the Angke Kapuk protected forest (Figure 4, Table 2).

This finding is comparable with other studies. The land covered by the protected forest in the wetlands in this study is dominated by the mangrove forests that produce mangrove litter. In the mangrove ecosystems, mangrove litter is the potential food source for benthic infauna. The benthic infaunal communities were associated with the decomposition of leaves in a mangrove forest. Based on the previous study, benthic infauna was present from the fifth day of *Rhizophora*'s leaf decomposition times (De Oliveira et al. 2011). Besides the availability of the mangrove litter as a potential food resource for benthic infauna, the protected forest is located adjacent to the sea. According to Metcalfe and Galsby (2007), the highest abundance was recorded in the soft, unconsolidated substrates of the seaward assemblage, with diversity and abundance decreasing progressively in the landward assemblages. The decline of benthic infaunal species, in particular oligochaetes and polychaetes, toward land was also observed in this study. The oligochaetes, followed by the polychaetes, were declining in the ecotourism park, which is landward and has fewer mangroves covered.

In contrast to benthic infauna that belongs to oligochaetes and polychaetes, in this study, benthic infaunal groups that belong to gastropods had a wider spatial distribution and tended to be contrasted with another benthic infauna that belongs to oligochaetes and polychaetes. In general, gastropods were more available in the ecotourism park and the eastern parts of the protected forest. On the contrary, the distributions of gastropods were limited in the areas characterized by a dense mangrove forest. In fact, gastropods preferred a wetland with the dominance of a water body combined with a water pond. The distribution of benthic infauna in brackish water areas is restricted by factors such as elevation, salt content, substratum, food, and respiration systems (Liu et al. 2014). Gastropod is a benthic infauna with a respiration system that depends on the gills (Koopman et al. 2016). It means that the gastropod requires an environment with stagnant water, also known as a tidal flat, to allow the exchange of oxygen from water between gills and water. Then the water bodies and fish ponds in the ecotourism park and eastern parts of the protected forest were suitable for gastropods since those areas resemble tidal flats due to inundations.

Shorebirds in the wetlands consisted of individuals belonging to Anatidae, Scolopacidae, Ciconiidae, Phalacrocoracidae, and Anhingidae (Figure 3) and density (Table 3). The shorebird species include Sunda teal (*Anas gibberifrons* S. Muller, 1842) for Anatidae, Common sandpiper (*Actitis hypoleucos* Linnaeus, 1758), Wood sandpiper (*Tringa glareola* Linnaeus, 1758) for

Scolopacidae, the Milky stork (*Mycteria cinerea* Raffles, 1822) for Ciconiidae, Little black Cormorant (*Phalacrocorax sulcirostris* Brandt, 1837) for Phalacrocoracidae, and the Oriental darter (*Anhinga melanogaster* Pennant, 1769) for Anhingidae. The ranges of H' for benthic infauna were 1.000-2.322. West parts of the protected forest have more shorebirds compared to east parts and ecotourism park. Anatidae, Scolopacidae, and Phalacrocoracidae are widely distributed in the protected forests and are limited to ecotourism parks. In contrast, Ciconiidae and Anhingidae were widely distributed in ecotourism parks and limited in protected forests (Figure 5, Table 3). The distributions of shorebirds were related to the habitat availability for nesting and food resources in the wetland ecosystems in the particular protected forests. Diverse mangrove species and muddy substrates characterize those wetlands. Dense mangrove covers, as seen in the protected forest, provide suitable habitats for coastal bird species by providing nesting sites for shorebirds who inhabit this forest. This finding is in agreement with previous studies. The Anatidae (Safe'i et al. 2021), Phalacrocoracidae (Da Silva et al. 2018), Scolopacidae (Desmawati et al. 2017; Sholihah 2017), and Anhingidae (Narayanan et al. 2012) known to have preferences for occupying the mangrove covers used as a nest and perch located on the mangrove forest's edge.

Benthic infauna and shorebird community coexistence

Figure 6 shows the coexistences and availabilities of benthic infauna to shorebird community based on K-means clustering and AIC values (Table 4) to show the correlation. Based on clustering analysis, there are 3 clusters. The first cluster consists of Ciconiidae and Anhingidae clustered together with gastropods with AIC values of 10.49-13.63. The second cluster consists of Anatidae, Scolopacidae, and Phalacrocoracidae clustered together with oligochaetes and polychaetes with AIC values of -4.36-10.49 indicating significant dependencies and correlations between the shorebird and benthic infauna. Finally, the third cluster only consists of crustaceans. From this cluster, gastropod was available to Ciconiidae and Anhingidae. Meanwhile, oligochaetes and polychaetes were available to Anatidae, Scolopacidae, and Phalacrocoracidae. In contrast, crustacea were not available to any shorebird communities.

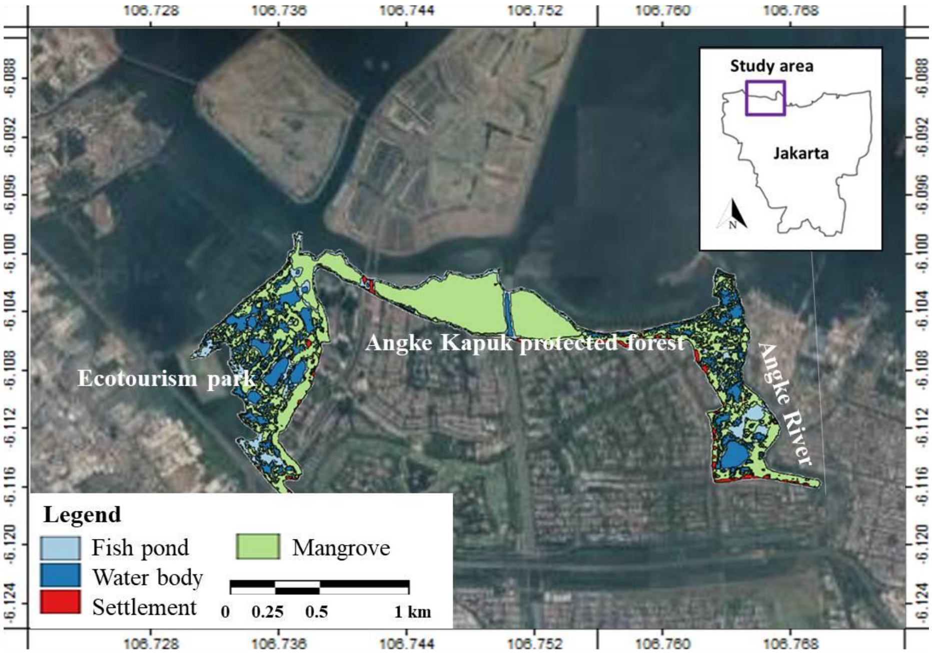

Figure 2. A map of the study area shows mangrove and land covers in the wetlands of the Jakarta Coast, Indonesia

Table 2. Average number and density (inds/100 m^2) of benthic infaunal species presences in each location (Jakarta Coast, Indonesia)

Benthic infaunal presences	Epk	Wpf	Epf	Total	Average (95%CI)
Polychaeta	150	400	150	700	233.33 (70.3, 396)
Oligochaeta	30	900	200	1130	376.66 (-145, 899)
Gastropod	200	180	200	580	193.33 (180, 206)
Crustacea	10	0	0	10	3.33 (-3.2, 9.86)

Note: Epk (Ecotourism park), Wpf (West parts of Angke Kapuk protected forest), and Epf (East parts of Angke Kapuk protected forest)

Table 3. Average number and density (inds/Ha) of shorebird species presences in each location and compared to other studies

Family	Species	Epk	Wpf	Epf	Total	Average (95%CI)	Other studies
Anatidae	*Anas gibberifrons*	1.72	4.68	3.12	9.52	3.17 (1.49, 4.85)	2.81 (Sugiarti et al. 2019)
Scolopacidae	*Actitis hypoleucos*	16.11	43.84	29.23	89.18	29.73 (14.0, 45.4)	0.22 (Martins et al. 2019)
	Tringa glareola	1.34	2.93	1.62	5.89	1.96 (1.00, 2.92)	1.65 (Fajrin et al. 2019)
Ciconiidae	*Mycteria cinerea*	1.78	2.17	1.43	5.38	1.79 (1.37, 2.21)	1.0 (Ronny et al. 2017)
Anhingidae	*Anhinga melanogaster*	2.37	3.56	1.30	7.23	2.41 (1.14, 3.68)	3.46 (Narayanan et al. 2012)
Phalacrocoracidae	*Phalacrocorax sulcirostris*	2.58	7.02	4.68	14.28	4.76 (2.25, 7.27)	

Note: Epk (Ecotourism park), Wpf (West parts of Angke Kapuk protected forest), and Epf (East parts of Angke Kapuk protected forest)

Table 4. Correlation and dependence models of shorebird species with benthic infaunal communities based on Akaike Information Criterion (AIC) values

Variables	Family	AICc	ΔAIC	AIC weight	AIC cum.	Log likehood
Anas gibberifrons ~ benthic infaunal species	Anatidae	10.49[b]	14.85	0	1	-14.24
Actitis hypoleucos ~ benthic infaunal species	Scolopacidae	10.49[b]	14.85	0	1	-14.25
Tringa glareola ~ benthic infaunal species	Scolopacidae	-4.36[a,b]	0.00	1	1	-6.82
Mycteria cinerea ~ benthic infaunal species	Ciconiidae	13.63	17.99	0	1	-15.81
Anhinga melanogaster ~ benthic infaunal species	Anhingidae	10.49[b]	14.85	0	1	-14.24
Phalacrocorax sulcirostris ~ benthic infaunal species	Phalacrocoracidae	10.49[b]	14.85	0	1	-14.24

Note: [a]best model, [b]significant correlation

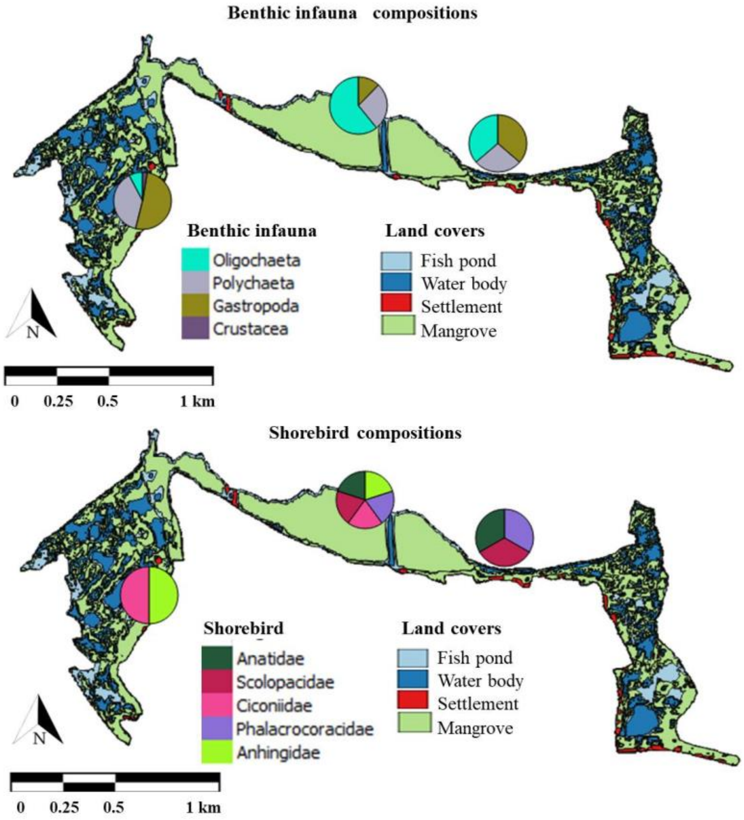

Figure 3. A map of the study area showing benthic infaunal and shorebird compositions in mangrove and land covers in the wetlands of Jakarta Coast, Indonesia

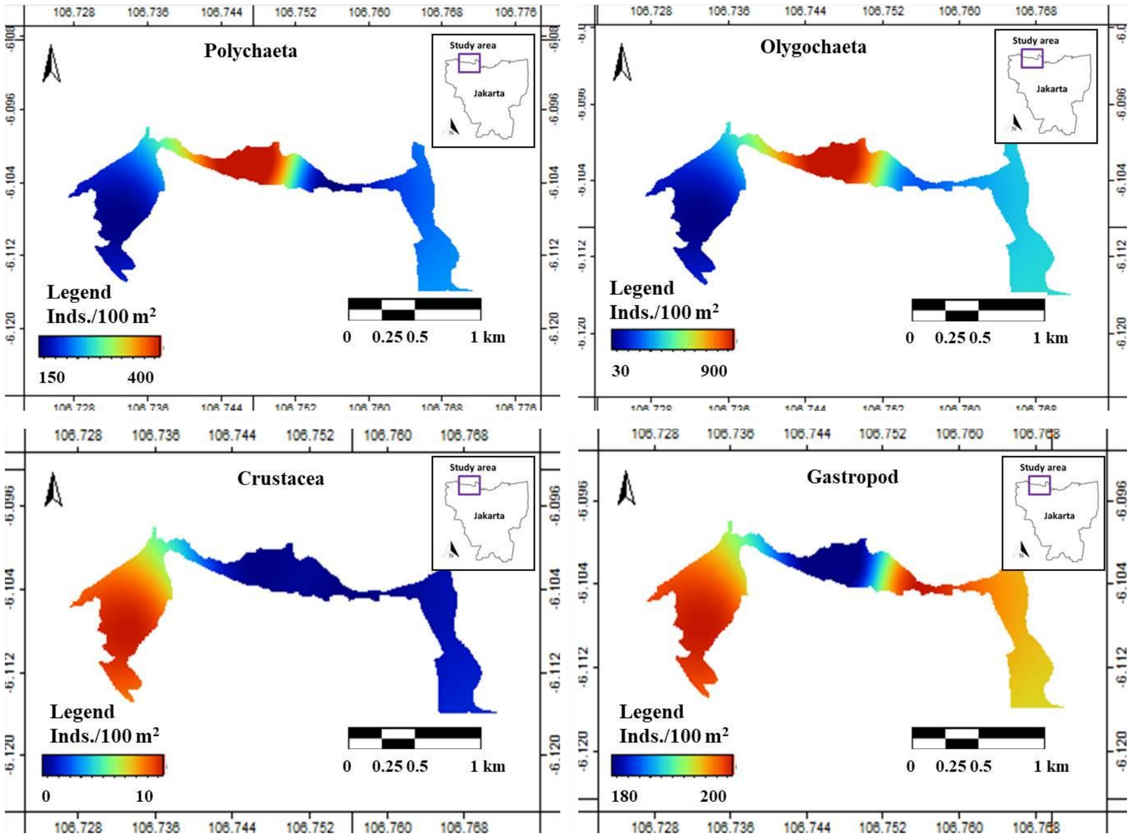

Figure 4. A map of the study area showing the density (inds/100 m^2) of benthic infaunal species presences in mangrove and land covers in the wetlands of Jakarta Coast, Indonesia

Discussion

This study identified significant relationships between shorebird and benthic infaunal communities, as reported before (Mouronval et al. 2007). The relationship was based on and influenced by the benthic infaunal availability, considering the benthic infauna is a food source for shorebirds. This prey availability explains the varied spatial distributions of shorebirds in the wetlands of the Jakarta Coast. The presence of shorebirds indicated the benthic infaunal availability since the presence of shorebirds followed the presence of benthic infaunal species. The shorebird species of Anatidae, Scolopacidae and Phalacrocoracidae were widely distributed in the west and east parts of the wetlands on the Jakarta Coast due to the availability of benthic infauna. In those parts of the wetlands, the west contains oligochaetes and polychaetes, and the east contains gastropods. In contrast, those shorebirds were not distributed to the ecotourism park despite the availability of gastropods. Shorebird distributions following the distributions of oligochaetes and polychaetes were in agreement with previous studies. In the wetlands of Aconcagua Estuary, visual foraging and tactile shorebirds, including American oystercatcher (*Haematopus palliatus* Temminck, 1820), Hudsonian godwit (*Limosa haemastica* Linnaeus, 1758), Lesser yellowlegs (*Tringa flavipes* Gmelin, 1789), Greater yellowlegs (*Tringa melanoleuca* Gmelin, 1789), Whimbrel (*Numenius phaeopus* Linnaeus, 1758), and Black-necked stilt (*Himantopus mexicanus* Statius Muller, 1776) foraged in wetlands with a high abundance of nereid polychaetes and oligochaetes, such that all of that benthic infauna were registered as being in the diet of those shorebirds (Pérez-Vargas et al. 2016).

The strong association between benthic infauna as prey and feeding shorebirds as predators is predictable. Shorebirds exhibit great dietary flexibility and combine specific prey selection and the opportunity to select the most abundant prey locally available. In this study, oligochaetes followed by polychaetes were very abundant compared to other benthic infaunal communities. Despite the abundance of gastropods in ecotourism parks and the east parts of protected forests, Anatidae, Scolopacidae, and Phalacrocoracidae abundances were low in those study areas. Low abundances of certain shorebird communities in some locations are related to the distance to the roost as a determinant factor (Bakker et al. 2021). Foraging patterns of shorebirds can be varied amongst wetlands in terms of the distance traveled between roosting and foraging sites. This explains the low abundance of Anatidae, Scolopacidae, and Phalacrocoracidae in the ecotourism park area since the distance between this area and the protected forest was more than 1 km.

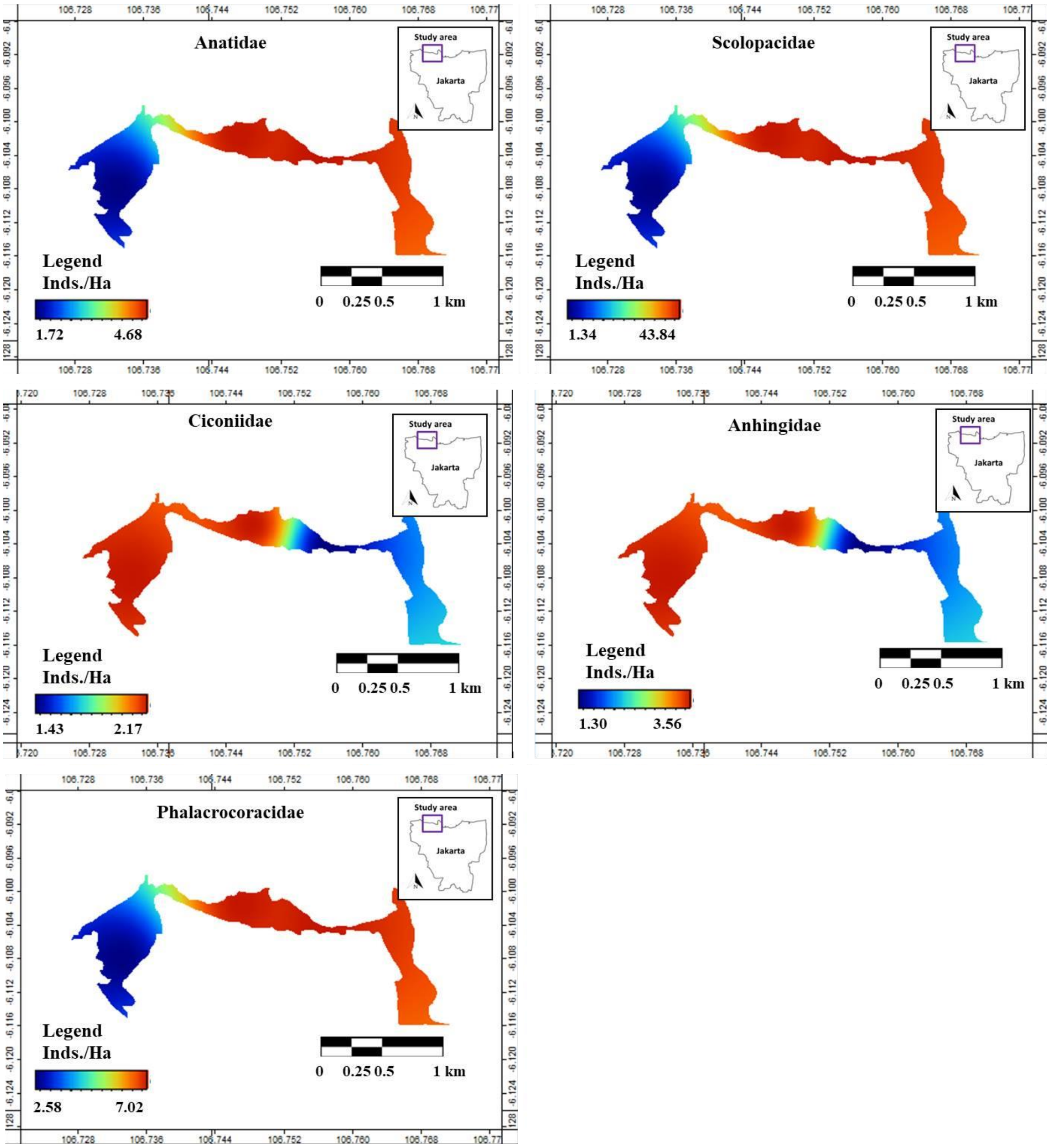

Figure 5. A map of the study area showing the density (inds/Ha) of shorebird species presences in mangrove and land covers in the wetlands of Jakarta Coast, Indonesia

The presence and abundances of shorebird communities belonging to the families Ciconiidae and Anhingidae in the ecotourism park were more closely related to their morphology (Alonso et al. 2011) which suited the conditions of the ecotourism park. Because of this adaptation, these shorebirds can forage in flooded ecosystems. In this study, an ecotourism park is characterized by the dominance of water bodies and fish ponds (Mulyani et al. 2021). Then, morphological characteristics of Ciconiidae and Anhingidae were adapted to the environmental conditions of ecotourism park area, and this may explain the presence of these shorebirds in this particular study area, besides the abundance of gastropods.

It can be concluded that based on the spatial analysis, K-Means cluster, and AIC analyses, the coexistence of shorebird communities in the wetlands of the Jakarta Coast depends on the availability of benthic infauna as prey, and the prey availability is associated with the quality of wetlands. Therefore, wetlands dominated by dense mangroves will lead to an abundance of benthic infauna and influence the presence and distribution of shorebirds. At present, oligochaetes followed by polychaetes are considered the most important food resources for shorebirds considering that this benthic infauna is available in large amounts compared to gastropods and crustaceans. Based on the benthic abundances and aiming to conserve shorebirds, it is recommended to conserve the mangrove forest, considering this forest is an important resource for benthic infaunal communities in the wetlands of the Jakarta Coast, Indonesia.

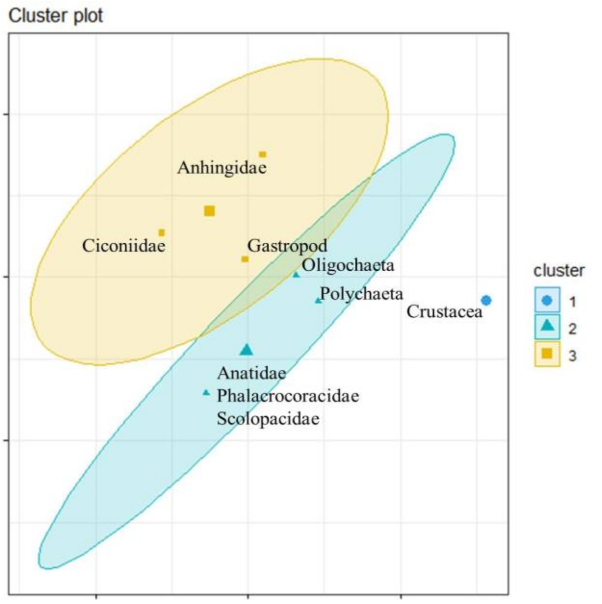

Figure 6. Availability and coexistence of benthic infaunal (Crustacea, Gastropod, Oligochaeta, Polychaeta) with shorebird (Anatidae, Scolopacidae, Ciconiidae, Phalacrocoracidae, Anhingidae) communities in the wetlands of Jakarta Coast based on K-means clustering analysis

REFERENCES

Alevizos E. 2016. Introduction to SAGA GIS. DOI: 10.13140/RG.2.2.31487.87206.

Alonso J, Alonso J, Carrascal L. 2011. Habitat selection by foraging white storks, *Ciconia ciconia*, during the breeding season. Canad J Zool 69: 1957-1962. DOI: 10.1139/z91-270.

Amarasekara EAKK, Jayasiri HB, Amarasiri C. 2021. Avifaunal diversity in urban coastal wetland of Colombo Sri Lanka. Open Access Libr 8: 1-10. DOI: 10.4236/oalib.1107256.

Andriyono S, Nindarwi DD, Kenconojatia H, Budia DS, Azhar MH. 2016. Dominance and diversity of seagrass and macrozoobenthos on transition season in Bama Beach, Baluran National Park, Situbondo. J Ilmiah Perikanan dan Kelautan 8 (1): 36. DOI: 10.20473/jipk.v8i1.11191.

Bakker W, Ens B, Dokter A, van der Kolk H, Rappoldt K, van de Pol M, Troost K. 2021. Connecting foraging and roosting areas reveals how food stocks explain shorebird numbers. Estuar Coast Shelf Sci 259: 107458. DOI: 10.1016/j.ecss.2021.107458.

Basyuni M, Gultom K, Fitri A, Susetya EA, Wati R, Slamet B, Sulistiyono N, Yusriani E, Balke T, Bunting P. 2018. Diversity and habitat characteristics of macrozoobenthos in the mangrove forest of Lubuk Kertang Village, North Sumatra, Indonesia. Biodiversitas 19: 311-317. DOI: 10.13057/biodiv/d190142.

Buda K, Budka M. 2019. Bird species detection by an observer and an autonomous sound recorder in two different environments: Forest and farmland. PLoS One 14: e0211970. DOI: 10.1371/journal.pone.0211970.

Chapman VJ. 2016. Coastal Vegetation. Elsevier, New York.

Da Silva TL, Cabral RBG, Ferreira I. 2018. Behavior and seasonal abundance of neotropic cormorant *Nannopterum brasilianus* (Gmelin, 1789) in southeastern, Brazil. Rev Bras Ornitol 26: 219-226. DOI: 10.1007/BF03544434.

D'Andrea R, Riolo M, Ostling AM. 2019. Generalizing clusters of similar species as a signature of coexistence under competition. PLoS Comput Biol 15 (1): e1006688. DOI: /10.1371/journal.pcbi.1006688.

De Oliveira A, Rizzo A, Da Conceicao E, Couto G. 2011. Benthic macrofauna associated with decomposition of leaves in a mangrove forest in Ilhé us, State of Bahia, Brazil. J Mar Biol Assoc U.K 92: 1-9. DOI: 10.1017/S0025315411001482.

Desmawati I, Trisnawati I, Kurnia O, Hamdani A, Fahmi M, Fahmi M. 2017. Distribution study on migratory bird (Scolopacidae: *Numenius*) in Surabaya, Indonesia: Estimating the effect of habitat and climate change. AIP Conf Proc 1854 (1): 020008. DOI: 10.1063/1.4985399.

Fajrin A, Halang B, Mahrudin. 2019. Species and density of trinil birds (*Tringa* sp.) at the Village Area of Sungai Rasau, Tanah Laut Regency as a handout material in animal ecological enrichment. Prosiding Seminar Nasional Lingkungan Lahan Basah 4 (3): 516-522.

Gaget E, Le Viol I, Pavón-Jordán D, Cazalis V, Kerbiriou C, Jiguet F, Popoff N, Dami L, Mondain-Monval J, Defos Du Rau P, Abdou W, Bozic L, Dakki M, EncarnaçãoV, Erciyas Yavuz K, Etayeb K, Molina B, Petkov N, Uzunova D, Galewski T. 2020. Assessing the effectiveness of the Ramsar Convention in preserving wintering waterbirds in the Mediterranean. Biol Conserv 243: 108485. DOI: 10.1016/j.biocon.2020.108485.

Hirsch P. 2016. Routledge Handbook of the Environment in Southeast Asia. Taylor & Francis, London. DOI: 10.4324/9781315474892.

Hutabarat AA, Yulianda F, Fahrudin A, Harteti Kusharjani S. 2009. Pengelolaan Pesisir dan Laut Secara Terpadu Bogor. PUSDIKLAT Kehutanan.Departemen Kehutanan RI SECEM-Korea International Cooperation Agency. [Indonesian]

Isworo S, Oetari PS. 2020. Mangrove vegetation and bird communities around Tegal Port, Central Java, Indonesia. Biodiversitas 21: 1551-1560. DOI: 10.13057/biodiv/d210436.

Katili AS, Utina R. 2019. Composition and abundance of Crustacea and Polychaeta in mangrove stands at Bulalo Kwandang District North Gorontalo Regency. Jambura Edu Biosfer J 1 (1): 32-40. DOI: 10.34312/jebj.v1i1.2044. [Indonesian]

Koopman K, Collas F, Van der Velde G, Verberk W. 2016. Oxygen can limit heat tolerance in freshwater gastropods: differences between gill and lung breathers. Hydrobiologia 763: 301-312. DOI: 10.1007/s10750-015-2386-y.

Liu W, Tanimura A, Imai T, Kanaya G, Niiyama T, Maegawa S, Kohzu A, Kimura T, Toyohara H. 2014. Distribution of gastropods in a tidal flat in association with digestive enzyme activities. Plankton Benthos Res 9: 156-167. DOI: 10.3800/pbr.9.156.

MacKinnon JR, Phillipps K. 1993. A Field Guide to the Birds of Borneo, Sumatra, Java, and Bali, the Greater Sunda Islands. Oxford University Press, UK.

Martins CO, Zakaria M, Olaniyi E, Angela UO. 2019. Population density of avian species in a man-made wetland of Peninsular Malaysia. IOP Conf Ser: Earth Environ Sci 269. DOI: 10.1088/1755-1315/269/1/012030.

Metcalfe K, Glasby C. 2007. Diversity of Polychaeta (Annelida) and other worm taxa in mangrove habitats of Darwin Harbour, northern Australia. J Sea Res 59: 708-82. DOI: 10.1016/j.seares.2007.06.002.

Mouronval J, Guillemain M, Canny A, Poirier F. 2007. Diet of non-breeding wildfowl Anatidae and Coot *Fulica atra* on The Perthois Gravel Pits, Northeast France. Widlfowl 57 (57): 68-97.

Mulyani Y, Putera A, Perwitasari-Farajallah D, Lhota S, Herliansyah R, Sodikin. 2021. Waterbird foraging habitat selection in Balikpapan Bay: water depth and patch area as important factors. Hayati 28: 312-324. DOI: 10.4308/hjb.28.4.312-324.

Murdiyarso D, Purbopuspito J, Kauffman J, Warren M, Sasmito S, Donato D, Manuri S, Krisnawati H, Taberima S, Kurnianto S. 2015. The potential of Indonesian mangrove forests for global climate change mitigation. Nat Clim Chang 5: 1089-1092. DOI: 10.1038/nclimate2734.

Narayanan S. Sreekumar B, Vijayan L, Thomas AP. 2012. Status of the nests of near-threatened oriental darter *Anhinga melanogaster* at Kumarakom Heronry. Natl Acad Sci Lett 35: 99-101. DOI: 10.1007/s40009-012-0027-9.

Obunga G, Siljander M, Maghenda M, Pellikka PKE. 2022. Habitat suitability modelling to improve conservation status of two critically endangered endemic Afromontane forest bird species in Taita Hills, Kenya. J Nat Conserv 65: 126111. DOI: 10.1016/j.jnc.2021.126111.

Orimoloye I, Mazinyo S, Kalumba A, Nel W, Ibraheem A, Ololade O. 2019. Wetland shift monitoring using remote sensing and GIS techniques: Landscape dynamics and its implications on Isimangaliso Wetland Park, South Africa. Earth Sci Inform 12: 553-563. DOI: 10.1007/s12145-019-00400-4.

Pérez-Vargas AD, Bernal M, Delgadillo CS, González-Navarro EF, Landaeta MF. 2016. Benthic food distribution as a predictor of the spatial distribution for shorebirds in a wetland of Central Chile. Revista De Biologia Marina Y Oceanografia 51: 147-159. DOI: 10.4067/S0718-19572016000100014.

Philiani I, Saputra L, Harvianto L. Muzaki AA. 2016. Pemetaan vegetasi hutan mangrove menggunakan metode Normalized Difference Vegetation Index (NDVI) di Desa Arakan, Minahasa Selatan, Sulawesi Utara. SOIJST 1 (2): 211-222. DOI: 10.31219/osf.io/c8k6j. [Indonesian]

Prasetyo E, Wulandari R. 2021. Richness, diversity, and conservation status of bird species in Maron Beach, Semarang, Indonesia. Quagga: J Pendidikan dan Biologi 13: 95. DOI: 10.25134/quagga.v13i1.3664. [Indonesian]

Rabalais NN, Baustian MM. 2020. Historical shifts in benthic infaunal diversity in the Northern Gulf of Mexico since the appearance of seasonally severe hypoxia. Diversity 12 (2): 49. DOI: 10.3390/d12020049.

Rija A, Mgelwa A, Modest R, Hassan S. 2015. Composition and functional diversity in bird communities in a protected humid coastal savanna. Adv Zool 2015: 1-7. DOI: 10.1155/2015/864219.

Ronny A, Gunawan H, Yoza D. 2017. Penentuan tingkat kepadatan dan sebaran populasi Bangau Bluwok (*Mycteria cinerea*) menggunakan drone di Pulau Basu, Indragiri Hilir. J Riau Biologia 2 (2): 81-89. [Indonesian]

Safe'i R, Sari RN, Iswandaru D, Latumahina FS, Taskirawati I, Kaskoyo H. 2021. Biodiversity and site quality as indicators of mangrove forest health Pasir Sakti, Indonesia. Ann Romanian Soc Cell Biol 25 (2): 4400-4410.

Sahidin A, Setyobudiandi I, Wardiatno Y. 2014. Struktur komunitas makrozoobentos di perairan pesisir Tangerang, Banten. Depik 3 (3): 226-233. DOI: 10.13170/depik.3.3.2150. [Indonesian]

Sahidin A, Wardiatno Y. 2016. Spatial distribution of Polychaeta at Tangerang Coastal Water, Banten Province. J Perikanan dan Kelautan 6: 83. DOI: 10.33512/jpk.v6i2.1102. [Indonesian]

Sahidin A. 2020. Buku Fauna Bentik; Studi Kasus Keanekaragaman Bentik di Perairan Tangerang Banten. Graha Ilmu, Yogyakarta. [Indonesian]

Sari WN, Melki, Putri WAE. 2022. Biodiversitas Polychaeta di perairan muara Sungai Musi, Desa Sungsang Sumatera Selatan. Maspari J 14 (1): 49-61. DOI: 10.36706/maspari.v14i1.16701. [Indonesian]

Sasongko DA, Kusmana C, Ramadan H. 2014. Management strategy of Angke Kapuk protected forest. J Pengelolaan Sumberdaya Alam dan Lingkungan 4 (1): 35-42. DOI: 10.19081/jpsl.2014.4.1.35. [Indonesian]

Sholihah R. 2017. Behavior and ecological study of marine birds in Alas Purwo National Park Southern Cost—Indonesia. KnE Life Sciences: 2017: 177-185. DOI 10.18502/kls.v3i4.702.

Sofian A, Harahab N, Marsoedi. 2012. Kondisi dan manfaat langsung ekosistem mangrove Desa Penunggul Kecamatan Nguling Kabupaten Pasuruan. J Biol El-Hayah 2 (2): 56-63. DOI: 10.18860/elha.v2i2.2208. [Indonesian]

Sofian A, Kusmana C, Fauzi A, Rusdiana O. 2019. Evaluasi kondisi ekosistem mangrove Angke Kapuk Teluk Jakarta dan konsekuensinya terhadap jasa ekosistem. J Kelautan Nasional 15: 1-12. DOI: 10.15578/jkn.v15i1.7722. [Indonesian]

Sugiarti S, Kaspul, Mahrudin. 2019. Kerapatan populasi itik benjut (*Anas gibberifrons*) di Desa Sungai Rasau, Kabupaten Tanah Laut sebagai bahan handout pengayaan mata kuliah Ekologi Hewan. Prosiding Seminar Nasional Lingkungan Lahan Basah 4 (3): 598-602. [Indonesian]

Sukojo BM, Arindi YN. 2019. Analisa perubahan kerapatan mangrove berdasarkan nilai Normalized Difference Vegetation Index menggunakan Citra Landsat 8 (Studi Kasus: Pesisir Utara Surabaya). Geoid 14 (2): 1-5. DOI: 10.12962/j24423998.v14i2.3874. [Indonesian]

Tomlinson PB. 2016. The Botany of Mangroves. 2nd ed. Cambridge University Press, Cambridge, UK.

Utami S, Anggoro S, Soeprobowati T. 2017. Bird Species biodiversity in coastal area of Panjang Island, Jepara, Central Java. Adv Sci Lett 23: 2498-2500. DOI: 10.1166/asl.2017.8655.

Wiraatmaja MF, Hasanah R, Dwirani NM, Pratiwi AS, Riani FE, Hasnaningtyas S, Nugroho GD, Setyawan AD. 2022. Structure and composition molluscs (bivalves and gastropods) in mangrove ecosystem of Pacitan District, East Java, Indonesia. Intl J Bonorowo Wetlands 12: 1-11. DOI: 10.13057/bonorowo/w120101.

Zhao Q, Basher Z, Costello M. 2019. Mapping near surface global marine ecosystems through cluster analysis of environmental data. Ecol Res 35: 1-16. DOI: 10.1111/1440-1703.12060.